OVERVIEW OF SUBREGIONAL MODELING

Introduction and Purpose

The primary goals and objectives of the *Lower East Coast Regional Water Supply Plan* (LEC Plan) include the conceptual design and evaluation of numerous structural improvements to the regional water management system within the Lower East Coast Service Areas (LECSAs), as discussed in **Appendix C**. In support of this objective, five high resolution ground water flow models were developed to allow the various proposed structural improvement plans to be evaluated and compared at the desired level of detail. The boundaries of these models are depicted in **Figure F-1**.

An evaluation of water supply improvements based on hydrologic models is necessarily made relative to both current and future base conditions (i.e., as is with no improvements). Additionally, the ability of hydrologic models to assess the benefits and impacts of the proposed improvements is usually realized through the systematic use of preselected performance measures. Examples of such performance measures would include, but not be limited to, stage duration curves for wetlands and reservoirs, ground water level hydrographs, and ground water flow across selected boundaries. In the evaluation of structural water supply alternatives for the LEC Plan, assessments of the benefits and impacts of proposed improvements were carried out by first constructing performance measure based graphics from the model output of each type of scenario simulation and then comparing the graphics across the simulations.

Each of the subregional models developed in support of the LEC Plan was used to perform this type of comparative analysis of the alternatives that were proposed within the respective model domains. To aid in developing an understanding of the common model features that are required to accomplish this objective, general discussions of typical features that are common to all of the subregional models are provided below. Specific details regarding the development and unique features of each model are provided later within this appendix.

General Features of MODFLOW

Once modeling objectives have been established and a preliminary understanding of the predominant hydrologic processes within each area of interest has been attained, a model code that can meet the model development and application objectives is selected. MODFLOW, a code created by the U.S. Geological Survey (USGS), was selected for this purpose for the following primary reasons:

- It has been widely accepted in the ground water modeling profession for over ten years.
- The code is well documented and within the public domain.
- The code is readily adaptable to a variety of ground water flow systems.

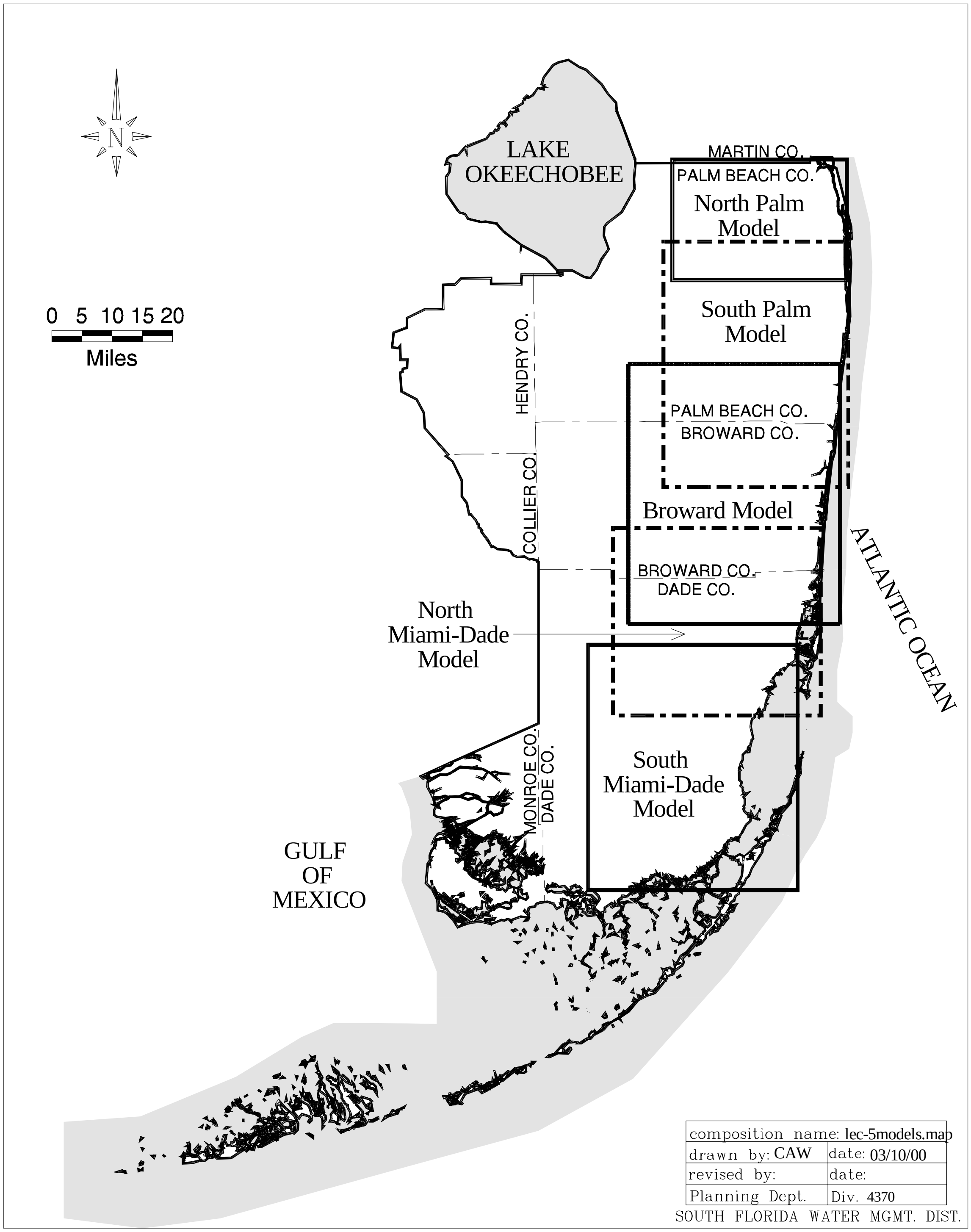

Figure F-1. Boundaries for the Lower East Coast Subregional Ground Water Models.

- The modular structure of the code facilitates any modifications required to enable its application to the types of unique ground water flow problems encountered in South Florida.
- MODFLOW was used to develop existing ground water flow models located within the LECSAs that could be upgraded to meet the current objectives.

MODFLOW simulates ground water flow in aquifer systems using the finite-difference method. The aquifer system is divided into rectangular or quasi-rectangular blocks by a grid (**Figure F-2**). The grid of blocks is organized by rows, columns, and layers, and each block is commonly called a cell.

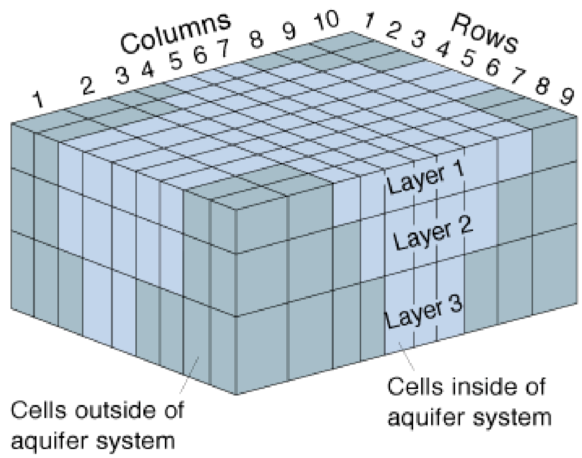

Figure F-2. Example of a Model Grid for Simulating Three-Dimensional Ground Water Flow.

For each cell within the aquifer system, the user must specify aquifer properties. Also, the user specifies information relating to wells, canals, and other hydrologic features for the cells corresponding to the locations of the features. For example, if the interaction between a canal and an aquifer system is simulated, then for each cell traversed by the canal, the required input information includes layer, row, and column indices; canal stage; and hydraulic properties of the channel bed. Also, MODFLOW allows the user to specify which cells within the grid of blocks are part of the ground water flow system and which are inactive (i.e., outside of the ground water flow system).

The MODFLOW model code consists of a main program and a series of independent subroutines called modules. The modules, in turn, have been grouped into packages which deal with a particular hydrologic process or solution algorithm. The packages used for LEC simulations, including those developed or enhanced by South Florida Water Management District (District, SFWMD) staff, are shown in **Table F-1**.

General Subregional Model Features

In addition to the application of the MODFLOW code, there are various other features that are common to each of the subregional models. Brief discussions of these features are provided below. In particular, it should be emphasized that certain types of input to these subregional models depend on the characteristics of regional water management systems and therefore need to be derived from the results of the regional model simulations (**Table F-1**). Consequently, a brief description of the relationship between the subregional models and the regional model, the South Florida Water Management Model (SFWMM), is also provided.

Table F-1. MODFLOW Packages Used in the LEC Subregional Models.

Package	Description	Notes
Core		
Basic and Output Control	Defines stress periods, time steps, starting heads, grid specifications, units, and output specifications	Handles the primary administrative tasks associated with a simulation
Block-Centered Flow	Specifies steady state vs. transient flag, cell sizes, anisotropy, layer types, and hydrogeologic data for each layer	Derived primarily from geologic data used to construct the model
Surface Water Stresses and Processes		
Recharge	Simulates aerially distributed recharge to a water table during each stress period	Preprocessed using an Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) based ET-Recharge model
Evapotranspiration (ET)	Simulates removal of water from the water table via transpiration and direct evaporation	Preprocessed using an AFSIRS based ET-Recharge model; ET rate diminishes with increasing water table depth
River	Simulates ground water interchanges with canals that can either recharge or drain the aquifer	Canal stages are usually based on measured stages, control elevations, or stages extracted from South Florida Water Management Model (SFWMM) output
Drain	Essentially the same as the River package except that canals can only drain the aquifer and water removed by the drains is removed permanently from the model	Canal stages are usually based on measured stages, control elevations, or stages extracted from SFWMM output
Canal	Essentially the same as the River package except it adds the capabilities to limit the drainage rate to a specific rate and the recharge rates to a different rate, as well as allowing separate control levels for recharge and drainage	When applied in combination with the wetlands package the controlled discharge is the combined total of surface water runoff and ground water seepage. When applied without the Wetlands package, the controlled discharge is the solely ground water seepage.
Redirected Flow	Essentially the same as the Drain package except that it allows water to be redirected to another location in the model instead of being permanently removed from the model.	
Lake	Simulates interaction between mining lakes (quarries) or reservoirs and the ground water system	Computes lake stages and performs an accounting of inflows/outflows; module was enhanced by District staff
Operations	Simulates the surface water transfer of water based on the availability of water	
Wetland	Simulates the overland flow in wetlands using the uppermost model layer	Enhanced to also simulate either specified or system dependant water diversions within wetlands
General Head Boundary	Simulates ground water exchange between selected cells and a specified boundary as a function of water level difference	Boundary stages are usually based on measured stages or stages computed by the SFWMM

Table F-1. MODFLOW Packages Used in the LEC Subregional Models. (Continued)

Water Supply and Management		
Well	Simulates withdrawals from wells	Includes Public Water Supply (PWS), irrigation, and Aquifer Storage and Recovery (ASR) wells; enhanced by the District to read multiple input files
Pumpage Reduction	Simulates wellfield withdrawal cutbacks as a function of water level in trigger wells and in Lake Okeechobee; simulates LEC water shortage policy associated with saltwater intrusion	Cutback zones are based on SFWMM, refined to include more details; SFWMM simulates the timing of Lake Okeechobee cutbacks
Reinjection Drainflow	Simulates the backpumping of seepage into impoundments by returning seepage collected in perimeter canals back to the impoundments	At the present, this module cannot be applied to impoundments that are relatively small or narrow
Solution Algorithms		
Strongly Implicit Procedure (SIP)	A mathematical solution algorithm internal to the model	Usually used
Preconditioned Conjugate Gradient (PCG)	A mathematical solution algorithm internal to the model; more computationally rigorous than SIP	Used only occasionally when model experiences convergence problems

Relationship to the SFWMM

The regional model covers the entire LEC Planning Area with two mile by two mile grids (square mesh) and simulates the systemwide hydrologic implications of a selected alternative. The SFWMM simulates the ground water system within its boundary using a vertically aggregated, single layer to mimic the composite effects of the nonhomogeneous surficial aquifer. Conversely, the subregional models typically use a stratigraphic, three-dimensional approach in which stratification within the surficial aquifer is simulated using multiple layers with intervening, semiconfining units that can transfer water from one layer to another. Furthermore, the ground water models typically consist of 500 feet by 500 feet spatial cells and up to seven layers. Both the regional model and the subregional models, however, have a stress period (i.e., a time increment for hydrologic stresses) and a time step (i.e., a time increment for numerical computation) equal to one day.

As with any hydrologic model, the use of these high resolution ground water models for a particular scenario requires both spatial and temporal information at their boundaries (i.e., at external boundaries and internal boundaries such as canals) along with information at locations of imposed hydrologic stresses (e.g., a pumping well or a structure discharging into a wetland). This information can include, but is not limited to, water levels, discharges at structures, recharge, potential evapotranspiration (ET), and withdrawals from Public Water Supply (PWS) wells. The nature of such information along with its derivation from the results of SFWMM simulations (where applicable) are discussed below.

Outer Boundary Conditions

The General Head Boundary package (**Table F-1**) is applied at all of the cells located along the ground water model boundaries. Water levels are therefore needed to simulate fluxes during all stress periods into and out of the model domain across the northern, eastern, southern, and western faces of boundary cells in all layers. Generally, the eastern face (**Figure F-1**) includes all of the coastal boundary cells and the water levels along this boundary are computed from the nearest tidal station with measured data. A correction is made to the computed head to account for the density difference between the salt water and fresh water. In addition, conductance associated with the general head boundary implementation is progressively reduced with depth (using a quadratic formula) to indirectly force the movement of fresh water towards the upper layers at the freshwater-saltwater interface. This is an approximation for the complex three-dimensional nature of flow dynamics that typically occur near the interface.

The water levels from the remaining faces of the model boundary (northern, western, and southern) are estimated from the SFWMM for all stress periods. For example, the water levels in the ground water model boundary cells located in the Water Conservation Areas (WCAs) are estimated from the corresponding water levels computed in the SFWMM simulation. Again, the same water level is assumed for boundary cells in all vertical layers. In some cases, a primary canal simulated by the SFWMM corresponds to the ground water model boundary. Where this occurs, the canal water levels resulting from the SFWMM run are used to define the heads at this boundary.

Initial Conditions

Similar to the concept of defining heads at a spatial boundary over time is the notion of defining heads at a temporal boundary over space. More specifically, water levels must be specified at each model cell at the beginning of a simulation (i.e., the temporal boundary). Water levels at the beginning of a simulation are derived from the output of the corresponding SFWMM simulation for the initial date (January 1, 1988). The first step in this process involves the use of Geographic Information System (GIS) based techniques to assign water levels corresponding to the SFWMM cells to each of ground water model cells in the respective two mile by two mile cells. Next, the resulting high resolution, initial water level surface is smoothed using the FOCALMEAN function of ARC/INFO. Finally, these initial head values are applied to cells in all layers.

Recharge and Evapotranspiration

For planning based applications of the high resolution ground water models, recharge and ET time series are computed using an ET-recharge model (Restrepo and Giddings, 1994). This is an extension of the Agricultural Field-Scale Irrigation Requirements Simulation (AFSIRS) Program (Smajstrla, 1990). The input rainfall for the AFSIRS model corresponds to the rainfall time series input for each of the SFWMM cells. Moreover, the potential ET rates required by this application are computed using the Penman-Monteith formula for a reference crop of dense grass cover 12 inches in height.

Unlike the rainfall data, the meteorological data necessary for this approach are obtained from selected stations in South Florida.

Canals

Since the River, Drain, and, in certain cases, the Reinjection Drainflow packages are used to represent the canals within a given subregional model domain, canals have been classified (somewhat subjectively) as either rivers or drains, depending on their characteristics. Regardless of the canal classification, however, canal stage time series are required for all canal reaches that are to be included in the model. Because the subregional model simulation periods are a subset of the simulation periods for the SFWMM, it is possible to extract canal stages computed by the SFWMM for a particular scenario for subsequent input to a subregional model. In particular, the canal stages were usually derived from SFWMM simulation results by using hydraulic grade line elevations and slopes computed by the SFWMM at specified locations to estimate hydraulic grade line elevations at all canal reaches included in subregional model simulations. Certain canal reaches, however, were either assigned fixed control elevations or stages that reflect other operational protocol not simulated by the SFWMM (e.g., various canals within Lake Worth Drainage District).

Wetlands

The Wetlands package (Restrepo et al., 1998) was used to simulate overland flow in extensive wetland systems located within the model boundaries. This package enables the user to define a wetland layer as the top layer of the model grid while enabling the MODFLOW code to apply the physical laws of overland flow within this layer. Interactions between the wetland layer and the uppermost aquifer layer can also be accounted for.

In certain cases (such as in the South Palm Beach ground water flow model), there are interior structures (e.g., S-10s) which divert water from one wetland system to another (e.g., from WCA-1 to WCA-2A). In such instances, a diversion option in the wetland module is used to take water out from a group of cells in one area (say WCA-1) and spread it over the receiving wetland (say WCA-2A). Water can also be diverted into the model domain from external sources. For example, discharges into the model domain across water control structures at the model boundary need to be simulated using this type of diversion option.

Quarries

At certain locations within the LECSAs, the presence of large mining quarries can impact ground water flow. To account for this, interactions between quarries and the ground water flow system are simulated using the Lake package (Nair and Wilsnack, 1998). This package is essentially the same as a previous version of the Lake package (Counsel, 1998) but modified by District staff in order to better account for the high degree of interaction that usually exists between ground water and quarries located in the LECSAs. The Lake package conceptualizes lakes or quarries as sources or sinks with respect to ground water flow and allows stages within them to fluctuate with time. This can enable a MODFLOW model to simulate quarry stages in addition to ground water levels.

Pumpage

The types of ground water withdrawals accounted for in the subregional model simulations include PWS, irrigation, Aquifer Storage and Recovery (ASR), and seepage return. Withdrawals from PWS and irrigation wells in the subregional model simulations were based on current or future permitted allocations. ASR withdrawals and injections were based on local trigger water levels, as well as a daily accounting of available water determined by the SFWMM simulation of the given scenario. Pumpage from seepage return wells was based solely on the design flow rates for the wells and the pumpage was usually returned to the wetland layer at a designated location.

Interactions with GIS

The preceding discussions reveal that in order to apply the MODFLOW code to a specific ground water flow system, the engineer or hydrogeologist is faced with the voluminous task of defining or quantifying all of the required parameters for each active model cell. Such an endeavor requires a systematic and efficient means of managing large amounts of spatial data. In the case of the LEC subregional models, this would naturally suggest that a spatial database containing parameter based thematic maps or coverages is needed for each subregional area of interest. The most suitable means for constructing such a database is GIS.

The GIS software ARC/INFO was used to construct a separate GIS database for each of the subregional model domains. Each database contains numerous thematic coverages that span, at a minimum, the active model domain and contain the data required to construct model input data sets. Examples of such thematic coverages include land use, canals, hydraulic aquifer properties, wellfields, quarries, etc. Conversely, GIS databases were also set up to enable the conversion of certain model output (e.g., ground water levels) to thematic coverages. This greatly facilitated the visualization and review of simulation results.

Period of Record for Subregional Model Simulations

The period of record selected for the required water supply management scenarios was 1987 to 1990. Most of the entire LEC Planning Area experienced drought conditions that were close to 1-in-10 year drought conditions, enabling the scenario simulations to address issues related to a 1-in-10 year drought (required by HB 715). Also, since the drought conditions historically diminished over 1990, the use of the 1988-1990 period of record allowed for an assessment of postdrought recovery.

In addition to a three-year duration, the subregional model simulations were temporally discretized using constant stress period and time step lengths of one day. This relatively short time step interval was used to minimize the types of errors that can result from using too large of a time step (Lal, in press). Also, performance measures related to wetland hydroperiods or reservoir water levels can be assessed more accurately when daily stress periods and time steps are used.

Model Output

Table F-2 summarizes the different types of output that normally result from a subregional model simulation. It should be noted here that although flow based parameters were computed on a daily basis, most of them were summed over each month before they were written out by the model. This was done primarily to speed up model execution while also conserving disk space.

Table F-2. Various Types of Output Resulting from a Subregional Model Simulation.

Output Parameter	Output Time Increment
Wetland water levels	Daily
Specified wetland diversions	Monthly
System-dependant wetland diversions	Daily
Ground water levels	Daily
Ground water flows	Monthly
Quarry stages	Daily
Seepage return flows	Monthly